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FLEXIBLE EXIT CONE NOZZLE DEMONSTRATION FIRING RESULTS

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TECHNICAL REPORT AFRPL-TR-69-171

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EDWARDS, CALIFORNIA

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FOREWORD

This report was prepared by the Motor Component Development Branch, Solid Rocket Division, Air Force Rocket Propulsion Laboratory. Test firings were conducted under Project 305903 AMG, Solid Rocket Hardware Evaluation, with Lt John R. Ellison and Lt Steven J. Ojala acting as project engineers. This report pertains to a firing conducted during the month of March 1969.

This report has been reviewed and approved.

CHARLES R. COOKE
Chief, Solid Rocket Division
Air Force Rocket Propulsion Laboratory

ABSTRACT

This report describes the test firing of a thrust vector control system (TVC) on the AFRPL 40-inch-diameter Char motor. The TVC system (funded under Contract F04611-68-C-0004) consisted of a movable exit cone (Flex-X) nozzle and support hardware, which was designed to combine the advantages of the elastomeric seal with those of the supersonic split-line nozzle. The elastomeric seal failed approximately 1 second after motor ignition. Probable reasons for the failure, and a general description of preparations and motor performance are described in the text.

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SECTION I

INTRODUCTION

1. CONCEPT

The flexible exit cone nozzle is characterized by replacing a section of the exit cone with an elastomeric seal, thus allowing the exit cone to pivot for Thrust Vector Control (TVC). Cold-flow tests of the concept indicate that a side force amplification is obtained by proper placement of the flexible joint, thereby reducing the required nozzle vector angle for a given thrust vector angle. This factor, when combined with the reduced cost, light weight, simplicity and flexibility inherent in the Flex-X concept, provides a very positive incentive for pursuing the concept further.

2. OBJECTIVE

The test objective was to demonstrate the survivability of a flexible exit cone demonstration nozzle under a severe, 30-second duty cycle. A 30-second, 500-psig Char motor firing was utilized for the test firing.

3. TEST MOTOR

The motor used for the test was the AFRPL 40-inch Char motor. The Char motor is a reusable heavy-weight test motor that fires uncured propellant in an end-burning configuration. The motor is insulated with silica-filled buna-n rubber (V-46). The insulation is scraped clear between firings to remove char layers produced by previous tests.

The nozzle was instrumented with eight iron/constantan thermocouples, and chamber pressure was monitored by two pressure transducers.

4. DUTY CYCLE

The duty cycle used on this test is not typical of a mission-oriented duty cycle. The philosophy here was to investigate the extent of seal

erosion in the highly deflected positions. A subsequent nozzle, with a redesigned seal region (if necessary), will then be evaluated with a typical duty cycle. The duty cycle (Figure 1) thus consists of: (1) a ramp to full Yaw deflection and hold, (2) the same deflection cycle in the opposite direction, and (3) a series of steps to full deflection late in the firing, for the pitch plane. This duty cycle is not especially severe, but it does focus on the problem of seal survivability in deflected nozzle positions. The duty cycle proposed for the final demonstration test is more typical of a mission duty cycle. This final test will be a more realistic performance test.

5. PROPELLANT

The propellant used for this test was procured from the Atlantic Research Corporation. The formulation, ARCITE 427-B Modified, consisted of 22% Al, a PVC binder, AP oxidizer, and copper chromite burn-rate catalyst. Nominal flame temperature at 1000 psia was 5700°F. Additional ballistic property and motor performance data are found in Table I.

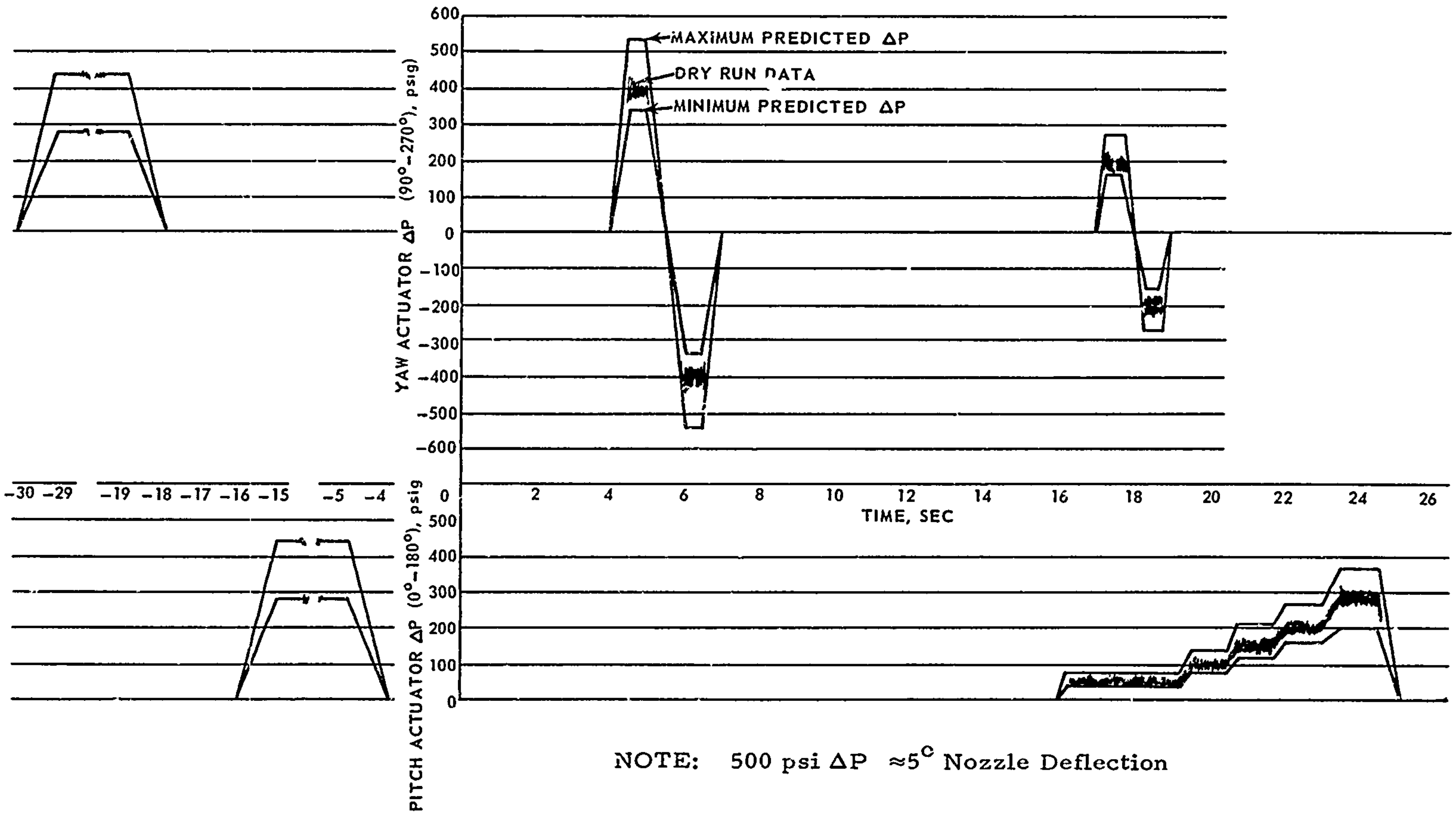

Figure 1. Duty Cycle: Actuator Δp Versus Time, Flex-X Nozzle Test No. 2 (Dry Run).

TABLE I. MOTOR AND NOZZLE DATA

Nominal Motor I. D. (Inches)		Nozzle Throat Diameter (Inches)		Propellant Depth (Inches)		Propellant Weight (Pounds)
Prefire	Postfire	Prefire	Postfire	As Loaded	Prefire	
37 5/8	37 7/8	3.794	3.814	17.6	17.6	1220

Ambient Temperature (^{o}F)	Ambient Pressure (psia)	Propellant Strand Burn Rate (in/sec)
78	13.7	$0.65\left(\frac{Pc}{800}\right)^{0.35}$

SECTION II

MOTOR PREPARATION AND PERFORMANCE

The AFRPL 40-inch Char motor was used for this test. A narrative of the motor preparation and performance follows:

Twenty-four hours prior to the motor loading, the silica-filled buna-n rubber insulation was coated with Hycar polymer to insure adequate wetting of the insulation by the propellant. Immediately before the propellant was cast into the motor, a second coating was applied. Approximately 1400 lbs of ARCITE 427-B Modified uncured gel propellant was then vacuum-loaded into the motor. Twenty-four hours later the aft closure and nozzle assembly were installed on the motor case, a $BKN0_3$ pellet bag igniter was placed 6 inches above the propellant surface, and the test was conducted.

Approximately 1/2 second after the ignition pulse, the flexible seal separated at the trailing edge. This occurred before the maximum chamber pressure had been reached. The exit cone was thrown clear of the aft closure, and remained suspended from the hydraulic lines at the side of the motor (see Figures 3 and 4). The throat remained in the motor, thus preventing a motor malfunction. Motor performance was excellent, exactly conforming to the predicted chamber-pressure-versus-time trace. This was the first AFRPL test using the ARC high-burn-rate propellant, and its perfect performance seems to have eliminated the erratic performance characteristic of earlier Char motor tests requiring a high-burn-rate propellant. The chamber-pressure-[illegible]s-time trace is shown in Figure 2. Additional motor performance date is [illegible] in Table I.

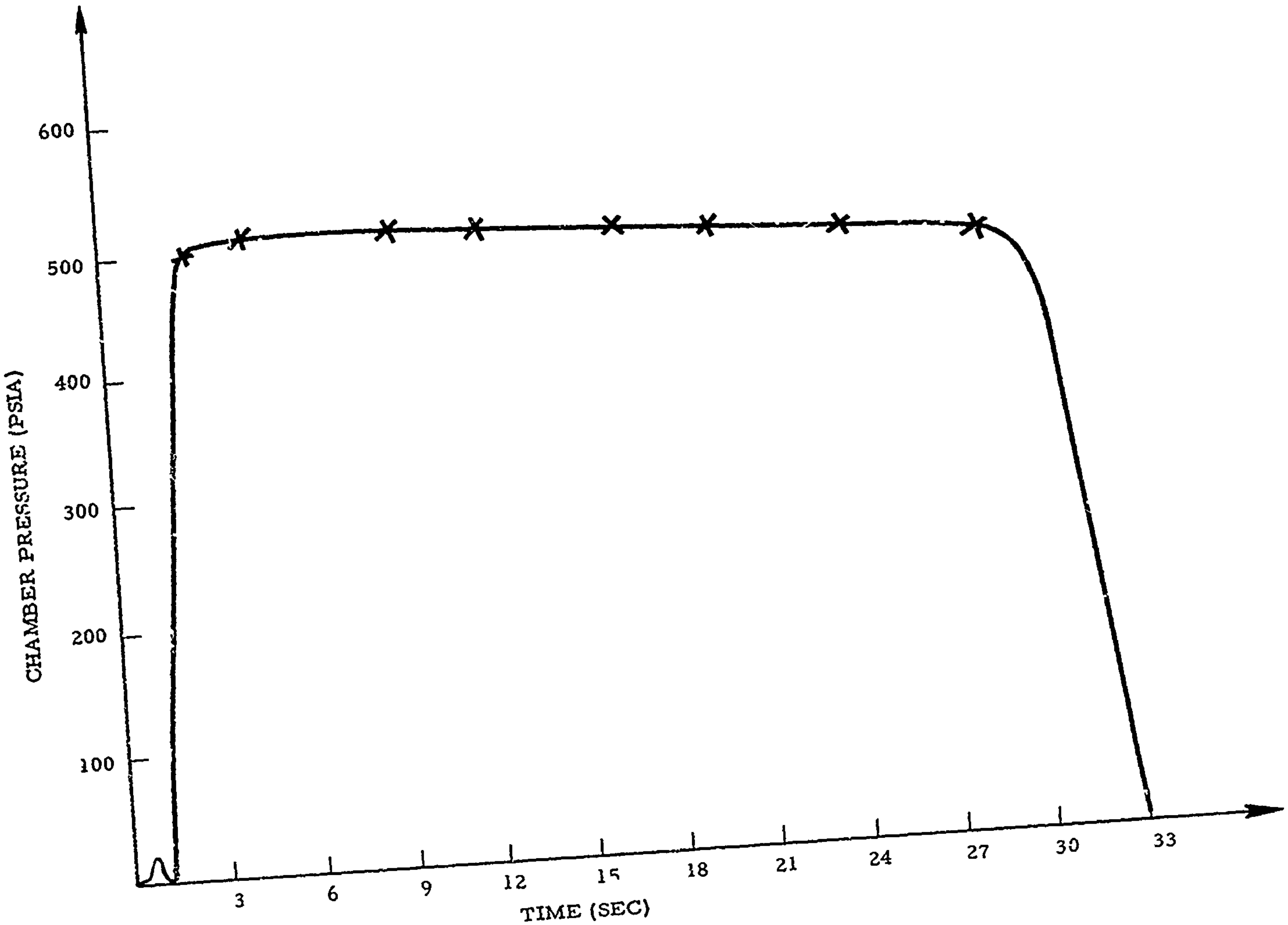

Figure 2. Chamber Pressure Versus Time.

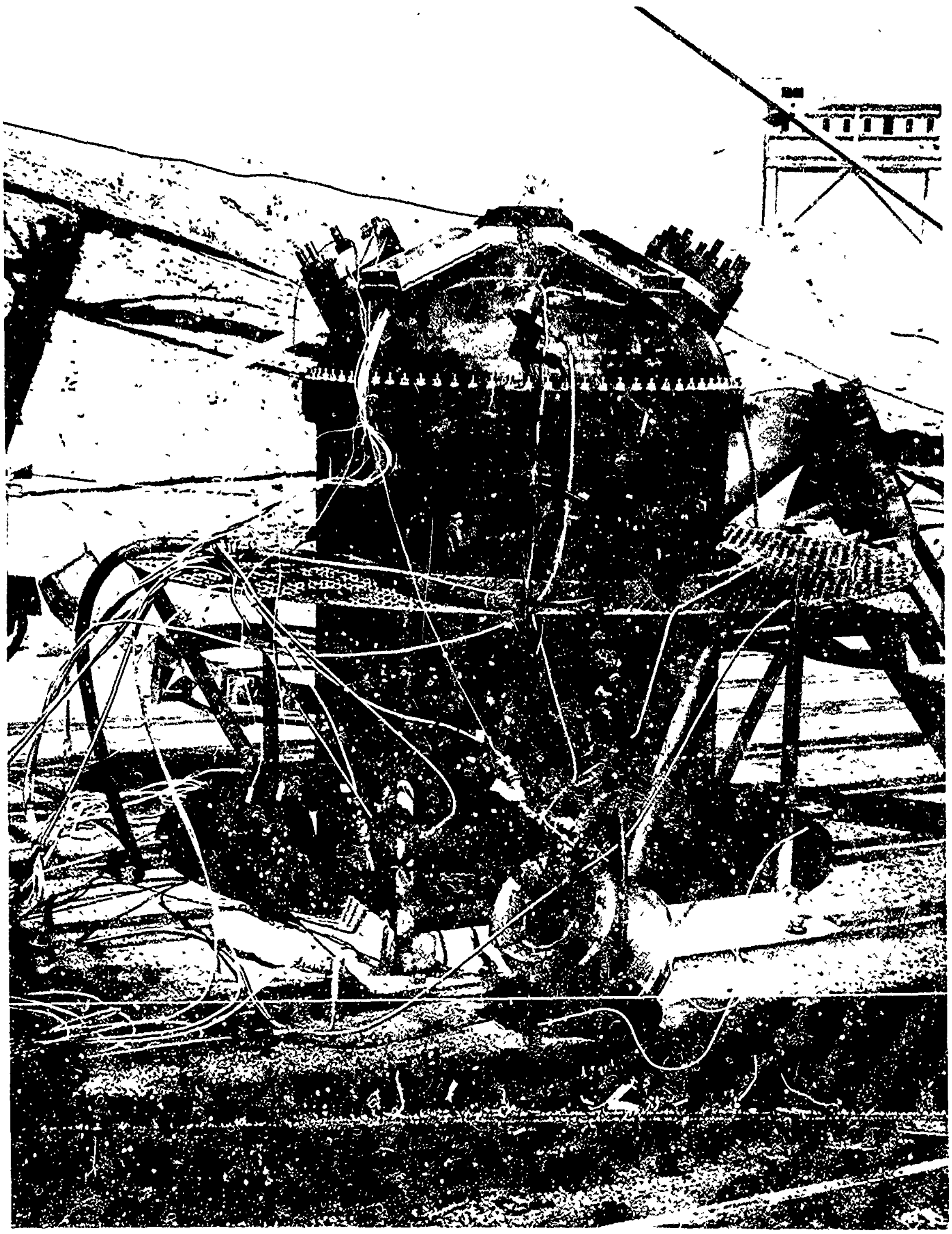

Figure 3. Postfire Overall View

Figure 4. Postfire Flexible Seal.

SECTION III

NOZZLE PERFORMANCE

The test nozzle was installed on the Char motor aft closure and the duty-cycle checkout performed under the direction of contractor personnel. Significant difficulties were encountered with noise in the actuator signal generating system. The noise was eliminated by adjusting voltage gain settings for the feedback potentiometers. Prior to the elimination of the noise, however, the test nozzle was deflected to an angle of approximately 10 degrees when an erroneous signal was generated. The nozzle actuation torque values of the final prefire duty-cycle trial run were checked to insure that no internal seal damage had resulted from the over-actuation (prefire view, Figure 5). Approximately 1 minute before ignition, AFRPL personnel reported that the hydraulic power supply pressure and actuator delta-P pressure signals appeared unnaturally unsteady. Thiokol personnel were consulted, and the hydraulic power supply was turned off and on by remote control. The signals still appeared to be unsteady, but the contractor informed the AFRPL personnel that the signals would smooth out when the duty-cycle tape started. The automatic countdown sequencer was initiated to turn on (in turn) the duty-cycle generator, motion-picture cameras, oscillograph, digital recording system, and ignition current. The nozzle was observed at all times on closed-circuit television by the Thiokol engineers, the test director, and the console operator.

The flexible seal of the joint assembly (Figure 6) failed almost simultaneously with motor ignition, much as described in Reference 1. Test firing data and movie coverage indicated that the nozzle had been deflected to over 5 degrees in both pitch and yaw, thus subjecting the seal to large asymmetric preloads at the most critical time of pressure transients. The immediate hypothesis was that this was the cause for the failure, because the seal had been evaluated by an extensive preassembly inspection program and found to be in excellent condition.

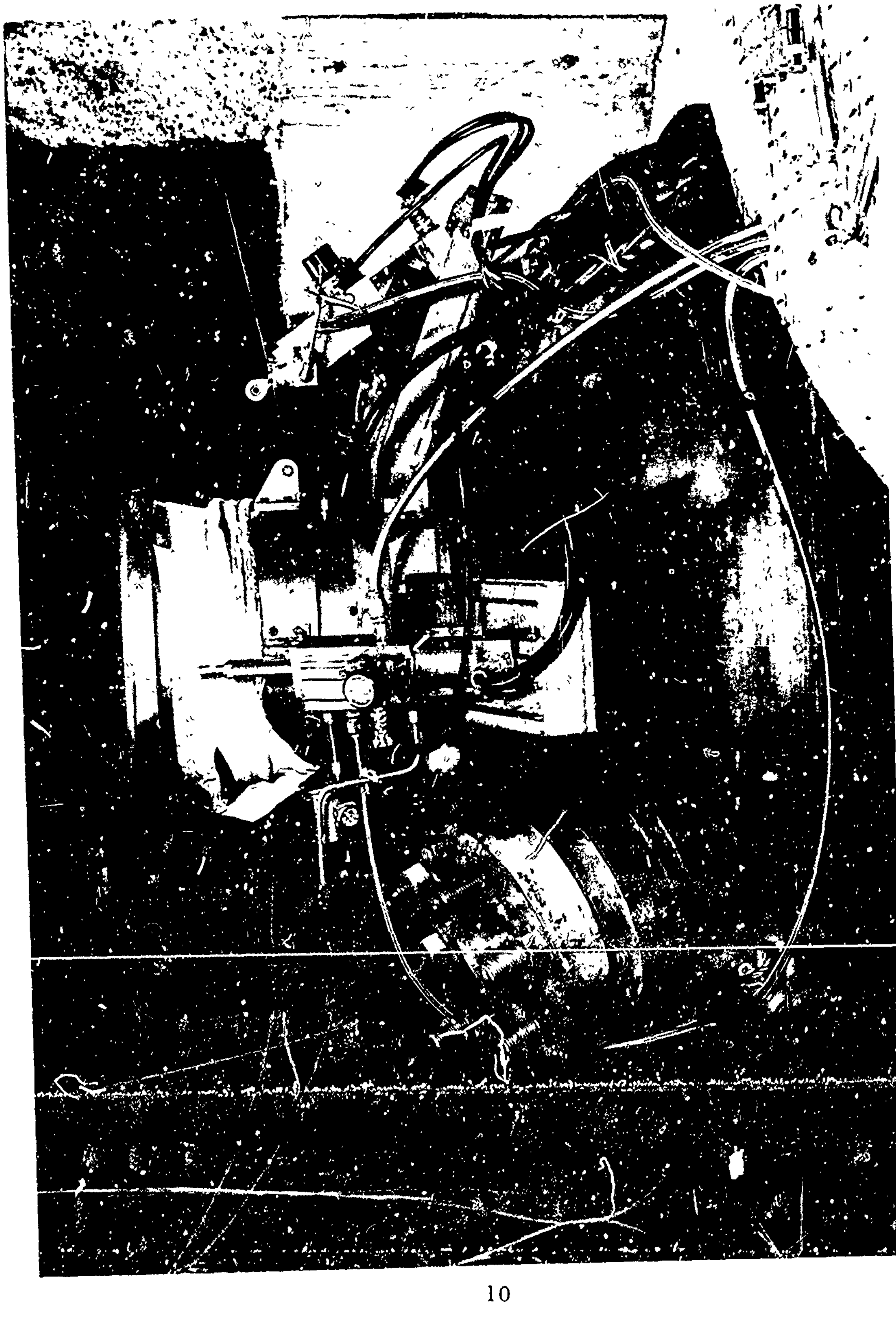

Figure 5. Prefire View of Test Nozzle.

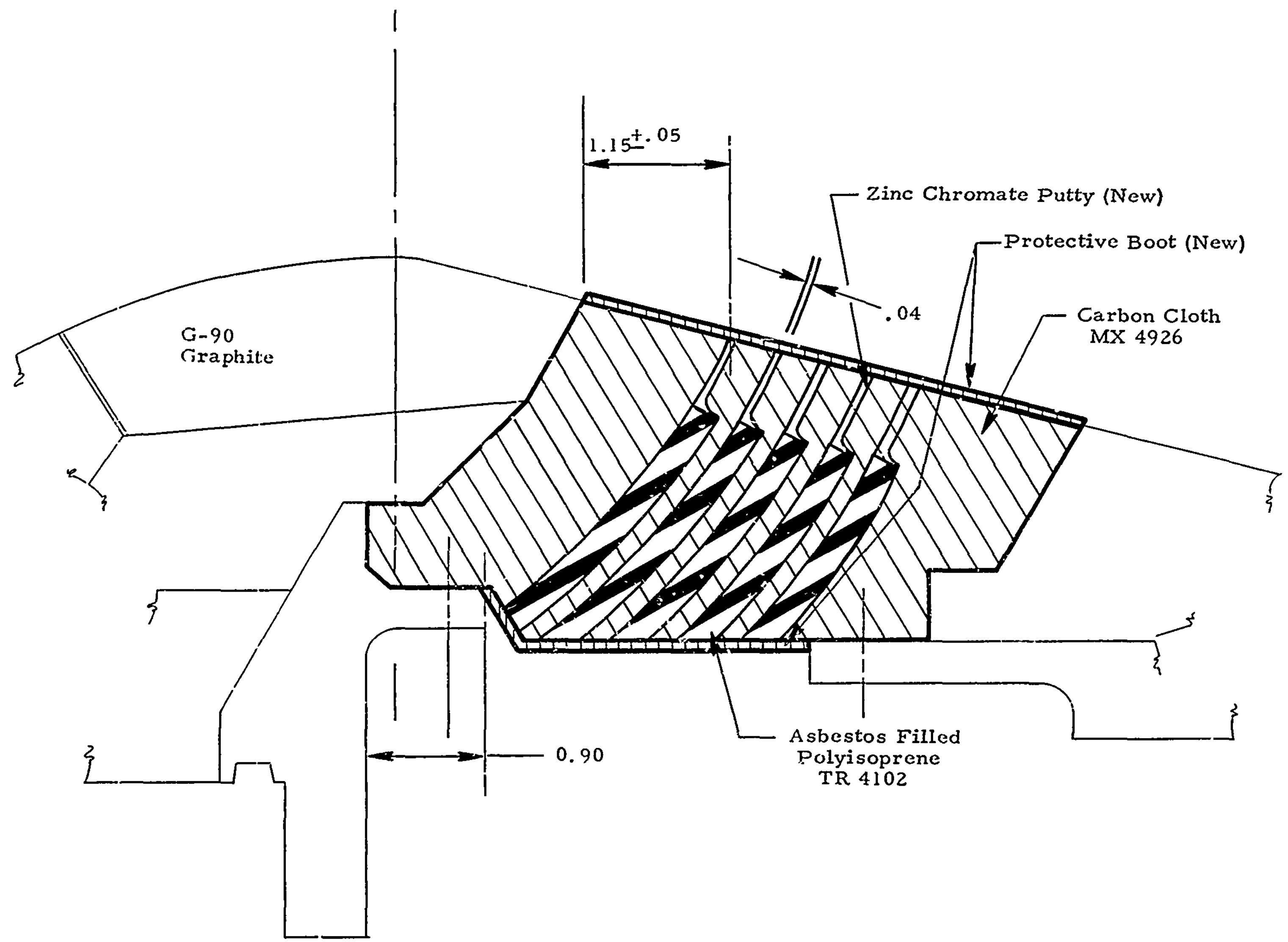

Figure 6. Joint Assembly,
Modified Recess Design.

The nozzle entrance cap and throat package performed much as expected, effectively preventing damage to the Char motor.

Postfire disassembly of the duty-cycle generator revealed that its timing control had malfunctioned because of an electrical short. The malfunction resulted in an accelerated tape speed with erroneous nozzle command signals

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations were made based on the test results:

1. The failure was a direct result of a control-system failure which resulted in the nozzle being in a vectored position during the critical pressure transient period.

2. Motor performance was excellent.

3. A repeat of the test with assurance of correct nozzle position at ignition is essential to prove or disprove the Flex-X concept validity.

4. The ARCITE 427-B modified propellant should be adopted as a standard Char motor test propellant.

REFERENCES

1. "Flexible Exit Cone Development Program - Materials Evaluation Test Results", AFRPL-TR-69-25, AD850752; Air Force Rocket Propulsion Laboratory, Edwards California, February 1969, Unclassified Report.

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